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Challenges and considerations for planning toward sustainable biodiesel development in developing countries: Lessons from the Greater Mekong Subregion

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ABSTRACT

Biodiesel has the potential to economically, socially, and environmentally benefit communities as well as countries, and to contribute toward their sustainable development. Nonetheless, the complex nature of biodiesel development makes it susceptible to exogenous problems that could hinder sustainable development. To ensure that biodiesel development actually leads to a sustainable path, all possible issues and challenges need to be identified and analyzed up front, so that they can be prepared for and handled in the planning and management stages. Building upon lessons learned from biodiesel developments in the Greater Mekong Subregion, this work examines biodiesel development in developing countries in the aspects of policy, governance, management, infrastructure, technology, feedstock, impacts on the rural poor and local livelihood, climate change, and the environment. Issues within each aspect are also analyzed in the context of developing countries. As a result, this review can serve as a guideline for ensuring that biodiesel development contributes toward sustainable development in developing countries.

Contents

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1. Introduction

As a renewable and alternative fuel, biodiesel has the potential to contribute toward sustainable development of many countries and regions. Nonetheless, whether or not the potential is fully realized depends on how the production, usage, and other related activities of biodiesel affect the economy, society, and the environment. Production and utilization of biodiesel promise bright prospects at community, national, and global levels. However, biodiesel developments are complex, affecting many stakeholders, especially the fragile environment and rural poor, in the cases of developing countries. The complexities of biodiesel development carry risks of exogenous problems that may indeed undermine sustainable development.

Careful planning and management are necessary to ensure that the production and utilization of biodiesel actually contribute toward sustainable development. There are many aspects to biodiesel development, and each aspect has many issues that need to be considered. All possible challenges must be identified and analyzed against the backdrop of ongoing developments and the status of the countries, in order to equip planners and managers with comprehensive understanding of the big picture.

This work analyzes the multiple aspects and issues of biodiesel development and adoption, especially in the cases of developing countries, and recommends consideration of points that should be incorporated in the planning stages. The points for consideration build upon viewpoints of stakeholders from various sectors who are closely involved with biodiesel development in developing countries. These points can serve as guidelines for future biodiesel projects, and for redirecting existing projects, to successfully contribute to sustainable development.

2. Biodiesel and its potentials toward sustainable development

2.1. Biodiesel overview

Biodiesel is an alternative fuel that is produced from biological sources, such as vegetable oils and animal fats, and gives similar performance to that of petroleum-derived diesel [1,2]. Biodiesel can be produced through many different methods involving thermal and chemical processes [3]. The four primary biodiesel production methods are direct use and blending, microemulsions, thermal cracking, and transesterification [1,4]. Of these methods, transesterification, which is a chemical reaction between triglycerides and alcohol in the presence of catalyst, is the most commonly used and widely accepted [1,2,5].

Biodiesel can be produced from the oils of many oilseed crops, as well as animal fats and waste cooking oils. Oilseed crops that have been used include canola, linseed, cottonseed, soybean, peanut, rubber seed, tobacco seed, sesame, microalgae, groundnut, Jojoba, mahua (*Madhuca indica*), and *Pongamia pinnata*; nevertheless, only palm, rapeseed, *Jatropha curcas* L., and sunflower have shown promising potential thus far [2,6]. Besides vegetable oils, animal fats and waste oils, such as beef tallow, waste cooking oil, waste flyer grease, and catfish fat, have also been used [4,7].

In most applications, biodiesel can be used to substitute diesel directly. Biodiesel can be used in normal diesel engines without any modification and has similar combustion characteristics to those of diesel [4,7]. Biodiesel can also be used in home heating, marine and jet applications, furnaces and boilers, and oil-fueled lighting equipment [7,8].

2.2. Potential of biodiesel toward sustainable development at the national level

Energy plays a crucial part in the development of every country, and biodiesel is one practical option that countries may add to their energy portfolios, as part of their sustainable development strategy. There is more than one way in which biodiesel can contribute toward sustainable development at the national level. Economically, biodiesel can serve as a relatively inexpensive domestic energy source, since it can be produced with locally available feedstock resources. Because biodiesel can be used as a substitute for conventional diesel, countries with biodiesel resources can essentially produce their own alternative fuel. Moreover, unlike diesel, which can be depleted, biodiesel is renewable. The prospect of having a renewable and domestically producible alternative fuel is undoubtedly desirable to countries that normally have to import crude oil or refined petroleum fuels, especially during periods of high oil prices. For these countries, domestic biodiesel development can lead to reduction in oil imports and lowering of national trade deficits. Additionally, with regard to national energy security, biodiesel can serve as a domestic energy source that is reliable and that can help reduce the dependence on fuel supplies from foreign countries.

2.3. Socioeconomic potential of biodiesel

Production and adoption of biodiesel as an alternative fuel may also create positive socioeconomic impacts that can eventually lead to sustainable development. Agricultural sectors and rural communities, in particular, can gain socioeconomic benefits from biodiesel development. For example, construction of biodiesel production plants and related infrastructure and maintaining feedstock crop plantations can help create jobs. Also, the demand for biodiesel feedstock crops can help expand and diversify markets for the feedstock crops. A more diversified agricultural market can offer more robust income revenues, which can especially benefit poor farmers with limited income options in rural communities. Furthermore, increased job opportunities and income in rural areas can bring about better rural livelihoods, which can contribute significantly toward countries' sustainable development.

2.4. Potential of biodiesel toward environmental protection

Perhaps the most recognized potential contribution toward sustainable development of biodiesel is its environmental prospects. In the use phase, biodiesel generally produces cleaner emissions than regular diesel. A technical study by the United States Environmental Protection Agency reported that the exhaust emissions from heavy-duty highway engines running on neat biodiesel had much lower amounts of particulate matter (PM), carbon monoxide (CO), and hydrocarbon (HC), compared to the emissions from neat diesel, although the amount of nitrogen oxides (NO_x) was higher by about 10% [9] (see Fig. 1). A more recent study reported that biodiesel emitted 54% less HC, 46% less CO, and 14.7% less NO_x, but 0.5% more carbon dioxide (CO_2) than diesel [10].

Besides cleaner emissions in the use phase, the whole lifecycle of biodiesel can also be environmentally friendly. Like all plants, biodiesel feedstock crops sequester carbon from the atmosphere. That initial negative balance of carbon may be enough to offset the amount of carbon emitted when biodiesel is combusted during its use phase. Consequently, the total amount of carbon emitted over biodiesel's lifetime may be zero or even negative. Nonetheless, the intermediate processes of biodiesel production, storage, and distribution may also result in carbon emissions. Thus, the

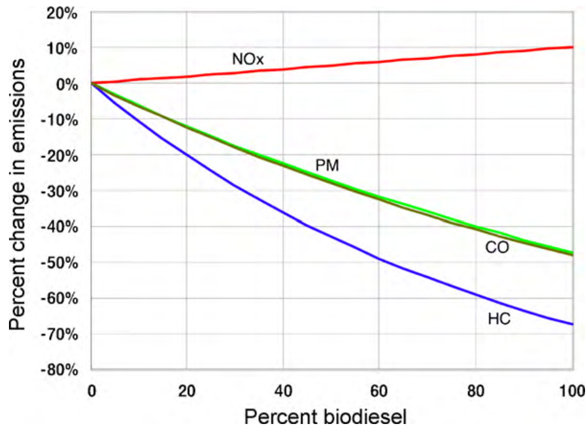


Fig. 1. Average emission impacts of biodiesel for heavy-duty highway engines [9].

lifecycle of biodiesel can be carbon-neutral or even carbon-negative, but only when certain types of feedstock crops and processes are utilized [11,12]. Given that transportation sectors around the world are continuously growing, the carbon-mitigating prospect of biodiesel could potentially offset the rise in carbon emissions due to increasing overall significance of transportation.

The planting of biodiesel feedstock crops can also make positive impacts on the environment. Some biodiesel feedstock crops like Jatropha can grow on marginal land, so they can be planted on otherwise unproductive, barren land. The plants can help rehabilitate degraded land and partially restore some of a forest's ecological functions, such as erosion control. Properly managed biodiesel feedstock plantation can, therefore, double as reforestation. Moreover, unlike diesel, biodiesel feedstock is renewable, so the use of environmental resources can potentially be sustainable.

2.5. Risks and complications

Despite the abovementioned potentials, biodiesel development sometimes also carries risks of environmental and socioeconomic problems that may actually undermine sustainable development. Developing countries are especially vulnerable to such risks. For example, land concession schemes might be used to facilitate biodiesel feedstock crop planting, but, without clear and stringent regulations, the concessionaires might encroach upon adjacent forestland. The ensuing forest clearance would not only seriously harm the environment and natural resources, but could also disrupt the livelihoods of local communities and cause social displacement. In another example, poor farmers, hoping to gain more income but lacking proper knowledge or guidance, might follow a biodiesel market rush and replace their existing crops with biodiesel feedstock plants, which might have been advertised to have a productivity that is, at most, speculative. After a few years of investing in the new plants, the unguided farmers might find that the actual yields are lower than speculated and end up with even less income than before.

Biodiesel development, especially on a large scale, is multi-staged and involves stakeholders from many sectors; thus, there are many aspects in which it can be susceptible to problems that hinder or counteract sustainable development. The multiple stages of biodiesel development range from policy drafting, to ensuring land availability, to feedstock crop planting, to biodiesel production, to standardization, to distribution, to utilization in the transport sector. During these stages, stakeholders may include policy makers, regulators, investors, funders, farmers, rural communities, environmentalists, researchers, biodiesel manufacturers, energy companies, fuel service providers, motorists, commuters, and international collaborators, for instance. In developing countries, the matter is not only complicated but also intricate, since especially vulnerable stakeholders, such as the rural poor and the already fragile environment, can easily get entangled in the development.

A thorough, multidimensional analysis of a biodiesel development project during the planning stages can help identify all potential risks upfront and allow corrective steps to be prepared, ensuring the contribution toward sustainability. Similarly, such analysis can be applied to an ongoing biodiesel project, in order to pinpoint ways in which it can be guided toward a sustainable path. Viewpoints of stakeholders from different sectors can often help identify areas of potential risks.

3. Biodiesel development in the Greater Mekong Subregion (GMS)

This work's recommended shortlist of points to consider, which should be analyzed and addressed in the planning and management stages of biodiesel development, is built upon viewpoints obtained from direct interviews with biodiesel stakeholders in the Greater Mekong Subregion (GMS), and results from related studies. This section provides an overview of the GMS and reviews its fuel demands, biofuels policies, and current biodiesel developments.

3.1. GMS overview

The Greater Mekong Subregion (GMS) comprises six East Asian countries sharing the Mekong River: Cambodia, Lao People's Democratic Republic, Myanmar, Thailand, Vietnam, and Yunnan Province and Guangxi Zhuang Autonomous Region of the People's Republic of China. Covering a land area of 2.6 million square kilometers, the GMS is home to about 325 million people and vast natural resources, including timber, minerals, coal, petroleum, and water from its many rivers, providing great potential for economic development [13–16] (Fig. 2).



Fig. 2. The Greater Mekong Subregion (GMS) countries [14].

The six GMS countries, with the Asian Development Bank's assistance, entered into a program of subregional economic cooperation in 1992 [13–16]. In 2002, the countries adopted a 10-year strategic development framework, with five developmental focuses: infrastructure linkages, cross-border trade and investment, private sector participation in development and competitiveness, human resources and skill competencies, and sustainable use of the subregion's shared natural resources [13–16]. Since then, the economies in the GMS have transformed through linked transportation, telecommunication, energy production and usage, and cross-border trade, leading to increased per capita incomes, improved education and health, and a better quality of life [17].

Nonetheless, the economic transformation has also inevitably brought about transformation of the natural environment. Evidence shows that ecosystems, species, and genetic resources are being lost at unprecedented rates [13–16]. Corrective steps need to be taken to alleviate this environmental depletion, and plans for sustainable development need to be established to allow the GMS countries to continue to sustainably develop, to avoid further harm to both natural and social systems.

3.2. Fuel demand in GMS

Like other developing countries, the GMS countries face growing demand for fuels and other forms of energy to propel their development, but most of the fuels, whether in the forms of crude oil or refined petroleum fuels, need to be imported. China's liquid fuel demand is the greatest of any country worldwide [18]. By 2020, China's imported oil is estimated to account for as much as 70% of the country's oil consumption [19]. Cambodia and Lao PDR are almost entirely dependent on imported oil. In Thailand, oil and natural gas account for 18.8% of total import values of goods in 2008 [20]. Even though Vietnam is a net exporter of crude oil, it still imported 12.85 million tons of refined petroleum oil in 2007 [21]. Moreover, the transportation sector in the GMS is projected to grow substantially, and the demand for liquid fuel will rise accordingly [22].

Thus, there is a real need in the GMS for domestically produced fuels. The economic and energy-security motivations are clear. There are also several environmental and socioeconomic reasons, as discussed earlier, that motivate the countries to fulfill their fuel demands by producing and utilizing their own biofuels such as biodiesel.

3.3. National biodiesel policies

The prospects of biodiesel have already been recognized in the GMS, as is evident in the development that has already taken place in all countries. However, the comprehensiveness of national biofuels policies and legislation still varies significantly from country to country.

In China, biofuels have rapidly gained ground in the energy policy arena and several plans and targets are already in place. In 2006, a target was set to meet 15% of transport energy needs with biofuels by 2020 [23]. According to one projection, this target will require 39–44 million tons of biofuels, or about 40 times the amount of China's 2005 biofuel production [24]. The province of Yunnan has been designated the national Jatropha demonstration province for biodiesel production [25].

Since embarking on biofuel development over 30 years ago, Thailand has put in place many biofuel policy measures, and the commercialization of biofuels has already begun in the consumer market countrywide. The range of biofuel measures includes investment promotion, biofuel standards legislation, feedstock productivity development, fuel tax incentives, vehicle specifications and tax incentives, research and development programs, as well as improvements in logistics and transportation networks. In terms of biodiesel commercialization, at present B2 (a 2% blend of biodiesel with conventional diesel) has been mandated in all commercial fuel stations since February 2008.

Vietnam has issued a Biofuel Master plan, which outlines the development of biofuel projects up to 2015, with an outlook to 2025. The government plans to invest USD 15.3 billion over 9 years (2007–2015). In response to the master plan, many organizations, including governmental offices, educational institutes, private companies, and NGOs, have launched their own initiatives related to their areas of expertise and responsibility.

Cambodia has a Renewable Energy Master Plan, but the plan prioritizes biomass, solar and mini-hydro power for rural electrification purposes and does not cover biofuels. A National Bio-energy Plan is still being developed, aiming to deal with issues such as land allocation, crop cultivation, taxation, standards for biofuels blending and distribution, emissions control, and applications for Clean Development Mechanism (CDM) carbon credits.

Lao PDR still lacks a comprehensive, institutionally supported approach to planning and implementing biofuels programs. Many ministries and agencies share the responsibility for biofuels development. Although a formal national biofuels policy has yet to be developed, the government supports the commercial production of appropriate oil crops as a substitute for expensive oil imports in order to strengthen the country's trade position.

3.4. Biodiesel development[1]

Although not all GMS countries have established clear national biofuels policies, biodiesel development is already underway and its pace is likely to accelerate in the medium term [26]. Examination of the ongoing biodiesel development in the GMS can help shed light on the issues, prospects, and risks associated with biodiesel development in developing countries.

Cambodia has recently seen substantial investment from both local and foreign sources, especially from Thailand, Malaysia, Korea, China and Singapore. These initiatives are implemented by private companies and are often driven by the availability of large areas of land (up to 100,000 ha) under economic land concession schemes. Five percent of Cambodia's national land area has already been granted to private companies for the development of agro-industrial plantations [27]. The biodiesel projects in Cambodia focus almost exclusively on Jatropha as feedstock crops. Large investors establish plantations on land leased under the concession scheme or arrange contract farming with farmers. However, most large-scale initiatives are still in the early stages of planning or implementation.

In Yunnan, private Jatropha development projects are limited to state-owned land. This is because land privately owned by village collectives is contracted to individual households, typically in small plots. Therefore, it is more difficult for investors to develop Jatropha projects on private land, since they would have to deal with a large number of individual smallholders to secure sufficient land area. Many companies in Yunnan are seriously considering commercial Jatropha plantations. Several refineries, reported to be under construction, have planned capacities on the order of 100,000 ton of biodiesel per year. Smaller companies also rent land from farmers and then hire the farmers for the plantation.

Similarly, the focus of both the government and the private sector in Lao PDR are on Jatropha as biodiesel feedstock. There is also significant interest from foreign investors. It was estimated in 2007 that 50,000 ha of Jatropha had already been planted in the

[1] The information on biodiesel projects in the GMS was obtained through site visits and interviews with stakeholders in their respective countries.

country, and the National Science Council forecasts that nearly 2 million ha of biofuels crops will be planted by 2020 [28].

In Vietnam, companies are currently focusing mainly on the feedstock stage of biodiesel production. Many are conducting small-scale experimental Jatropha plantations. A pilot plant that produces biodiesel from catfish fat is in operation at a major catfish company. In addition, a project to produce biodiesel from used cooking oil is being developed.

Thailand is the only Asian economy to date to embrace biofuels in the main consumer market, where biodiesel blends are available at fuel stations nationwide. As of August 2009, there were 13 licensed commercial biodiesel producers, with a combined production capacity of about 4.46 million liters (ML) per day [29], although the actual production average about 1.5 ML per day. Already over 3400 fuel service stations offered B5, or diesel with 5% blend of biodiesel. Besides the industrial-grade biodiesel that is commercially available, community-grade biodiesel, which is subjected to less stringent specifications, is also promoted.

4. Key elements of biodiesel development and issues for consideration

There are several important elements of biodiesel development in developing countries, each of which contains issues, prospects, and risks that should be considered and addressed in planning and management stages. Although these elements and issues are directly related to biodiesel development in the GMS, they can generally be applied to biodiesel development in other developing countries as well.

4.1. Policy

Despite much interest from governments and private investors in biodiesel development, many developing countries still lack coherent biofuel policies and credible long-term development plans. Ad hoc governmental initiatives could result in fragmented institutional responsibilities and ill-defined inter-organizational roles. Instead, an integrated national strategy that involves all relevant ministries and engages at both the national and the provincial levels should be employed.

Policies that address specific areas of biodiesel development are needed in conjunction with long-term strategic policies, as a long-term strategy alone is insufficient. Stakeholders are often skeptical when only a broad, long-term strategy is announced and usually want to see more concrete government commitment. More specific policies are critical in the early stages, in order to both show real commitment and ensure success in the later stages. These policies are needed in many areas, including investment promotion, biofuels tax incentives, land-use preferences, biofuels standardization, vehicle specification, and logistics, transportation, and distribution of biofuels.

Incentive policies are particularly important for stimulating new biodiesel development, especially when it is tied to speculative technologies or feedstock options. Most investors and farmers are reluctant to commit to major investments in a speculative venture. For instance, both supply and demand for Jatropha are inadequately developed in most countries where Jatropha biodiesel is being promoted. On the supply side, farmers are still reluctant to invest in planting Jatropha on a large scale, unless they can be assured of demand when the Jatropha seeds are ready in 3–5 years. On the demand side, biodiesel producers are reluctant to invest in refining facilities without a guarantee of adequate year-round feedstock supply [25]. A proper incentive structure is necessary to jump-start the supply chain. Moreover, a policy to ensure equitable distribution of benefits along the supply chain can help bring more stakeholders on board.

Using land concession schemes as policy tools to incentivize investors to invest in large-scale biodiesel development is effective yet risky. Some developing countries, such as Cambodia and Lao PDR, use land concession schemes to grant large tracts of land to private companies for investment in biodiesel feedstock crop plantations. Such schemes can effectively attract investors and jump-start countries' overall biodiesel development. However, the schemes are also susceptible to exploitation. A policy to safeguard natural resources and local livelihoods from being exploited by land concession schemes is essential.

Policies on standard specifications of biodisel are also crucial. Mandatory standards for biodiesel can ensure the fuel's quality, performance, and environmental characteristics. Having standardized biodiesel specifications can help generate confidence in the consumer market as well. Moreover, if there is a policy to promote widespread adoption of biodiesel across borders, the biodiesel standards of the countries involved need to be coherent.

Securing sufficient funding for biodiesel development may be challenging, but it is also critical. Insufficient funding can lead to weak implementation and lax enforcement of policies. International assistance can significantly contribute not only in terms of funding but also in other aspects, such as expertise in policy formulation, and developing greater coordination and coherence between ministries.

Additionally, alternative policy options that contribute toward the same overarching goals of sustainable development should be considered in parallel. Harmonized cooperation with other sustainability pathways will make the biodiesel pathway more successful.

4.2. Governance and management

Proper governance and management are crucial to ensuring that biodiesel development actually contributes toward sustainable development of a society. Without governance or management, biodiesel development may stray off course and lead to counter-sustainability problems.

Stringent monitoring is necessary when land concession schemes are used to incentivize investment on large-scale biodiesel crop plantations. The concessionaire's declared intent needs to be verified once approval is given. Otherwise, the schemes could be exploited. For instance, opportunistic investors may use a biodiesel crop plantation to cover up illegal logging. The availability of concession land for forest clearing has emerged as a serious issue in many developing countries. Such exploitation can severely harm the natural resources and livelihoods of local people. Training in areas such as land management, zoning, and land-use monitoring is needed to contain the potential abuse of the land concession schemes.

In areas where large-scale biodiesel development must involve a large number of farmers to supply feedstock for biodiesel production, management of the feedstock supply chain can be challenging. For example, in Yunnan, PRC, the use rights of a significant amount of barren land are granted to individual households, while village collectives own the land; because each village collective's land endowment is typically small, a large-scale Jatropha plantation will likely involve hundreds of thousands of households [25]. Coordinating the supplies from a large number of farmers, in order to ensure an appropriate amount of feedstock for production, requires comprehensive supply-chain management. Otherwise, the supply chain can become too fragmented to function.

4.3. Infrastructure

Infrastructure for refining, distribution and storage of biodiesel determines the extent to which biodiesel can contribute toward

the sustainable development of a society. A country with only biodiesel refining infrastructure, but without storage or distribution infrastructure, can only promote the use of biodiesel near production areas. If widespread utility of biodiesel for the transportation sector is targeted, major investment by both public and private sectors in large-scale infrastructure is critical.

Logistics of the production chain can be a key supplement to the infrastructure. For instance, when spoilage of biodiesel is an issue and the storage infrastructure is scarce, using smart logistics in conjunction with the distribution infrastructure can be an effective and inexpensive solution.

Much of the necessary infrastructure is still missing or underdeveloped in many developing countries. Governments alone may have limited resources to develop large infrastructures. Investment from the private sector and assistance from international developmental organizations are important elements.

4.4. Appropriate technology and feedstock

Challenges related to technology and feedstock are often more easily perceivable than issues in the other areas, since most biodiesel endeavors, especially those in developing countries, focus primarily on the technical and feedstock aspects of the projects. Nonetheless, many issues may still be overlooked.

Not only should biodiesel feedstock crops be profitable, suitable to local climate and soil conditions, and have high yields, but they should also produce consistent yields and high oil content and not compete with the production of food crops. Many developing countries choose Jatropha for feedstock because it can grow in a variety of landscapes, including barren land that is unsuitable for growing other crops. Jatropha can also grow and survive without much care, so it can have a higher energy return on investment and lower CO_2 footprint than other oil-bearing crops such as soybean or rapeseed. However, the seed yields and oil content of naturally grown Jatropha may not be as high as those of well-fertilized Jatropha. In general, achievable oil content and seed yields of Jatropha are still very uncertain and vary greatly from strain to strain. Farmers often cannot be certain that they have a high-quality Jatropha strain and may need to wait up to 3 years for the trees to bear seeds to find out.

Alternative uses and markets of biodiesel feedstock crops should also be considered. Moringa can be used to produce natural medicinal or spa products. The seed cake of Jatropha can be used as animal feed and organic fertilizer. These additional uses help diversify the markets of biodiesel feedstock crops and provide farmers with more flexible means of income.

Technologies for biodiesel development in developing countries should be affordable as well as suitable to the local conditions and feedstock. They can be a key to make certain local feedstock crop options become more viable. For example, crude Jatropha oil usually goes rancid quickly, so farmers cannot keep the oil for prolonged periods of time. An improved storage technology can prolong the life of the oil and give the farmers more time to wait for a better price. Technologies for more efficient crop harvesting and oilseed extraction can help increase the productivity of feedstock crop farming. Biodiesel production technologies in developing countries are usually imported or transferred through international assistance. Without adequate training for local operators and without properly adjusting the machinery to local operating conditions, transferred biodiesel technologies may stop functioning not long after being installed.

4.5. Impacts on the rural poor and local livelihood

Because most biodiesel projects in developing countries involve feedstock crop plantations in rural agricultural areas, farmers and local livelihoods are usually affected by the development. Several prospects and pitfalls are foreseeable.

On the positive side, biodiesel operations, even on a small scale, can enhance rural incomes at individual and community levels. Poor farmers can plant biodiesel crops on their marginal land to earn additional income. For example, a study estimated that a smallholder Jatropha program in Lao PDR could raise farmers' net incomes from land by 75% in the uplands [30]. In addition to agricultural revenues, the labor requirement for feedstock crop plantations and infrastructure construction also generate jobs and income opportunities in the rural areas.

Additionally, local use of biodiesel can improve the quality of life in rural communities. Farmers can produce and use biodiesel in their own agricultural machines and vehicles. Biodiesel can also be used for rural electrification, which can create immensely positive impacts in many developing countries. Only about 7–8% of the rural population in Cambodia, for instance, has access to electricity. Also, it is estimated that energy crops could supply up to 40% of the Lao PDR's rural off-grid electricity needs [31].

However, there is a danger that all farmers in a single area might follow short-term market price increases and rush to plant the same crops, making the whole community vulnerable to market volatility and price crashes. For crude Jatropha oil, which cannot be stored for more than a few days, there is an additional risk of unscrupulous buyers exerting price pressure on farmers desperate to sell before spoilage starts. Certain choices of feedstock materials for biodiesel production, such as Jatropha or Moringa, will benefit poor farmers more than others, such as catfish fat, an industrial factory by-product.

Moreover, land concession schemes that are used to promote investment in large-scale biodiesel projects may be subject to abuse and may impact negatively upon the livelihoods of rural communities. Examples of encroachment on agricultural and forest land, loss of collective land ownership by communities, disruption of access to roads and water resources, loss of income and social displacement have all been documented by non-government organizations. Far from contributing to rural livelihood development, land concessions can directly lead to land conflicts and the social dislocation and alienation of local communities from their lands.

4.6. Climate change and the environment

Planting of biodiesel feedstock crops can help rehabilitate degraded land and partially restore ecological functions. For instance, crops such as Jatropha, which can grow on barren land, can be used to restore soil erosion control to identified zones of marginal land.

Also, large-scale planting of biodiesel feedstock crops can help reforestation, but only when supported by detailed scientific study and comprehensive planning. Reforestation is a delicate endeavor, so poorly managed biodiesel crop plantations may not only fail to supply adequate feedstock but also harm the nearby forest land. Just like other types of agro-commodity productions, poorly managed biodiesel crop plantations carry high risks of adverse environmental impacts, including loss of biodiversity, competition for natural resources such as water and fertilizers, and degradation of soil quality. Such effects on the surrounding ecosystems must be predicted and avoided.

The potential for greenhouse gas mitigation of feedstock crop plantations is non-trivial, but may be very small compared to the total emissions of many countries. For example, a general estimate of greenhouse gas reduction by Jatropha biodiesel is 2.6 ton of CO_2 per kiloliter-year [31]. According to this estimate, Jatropha plantations planned in Southwest China can potentially offset 0.9–5.6 million tonnes per year of CO_2 emissions [25]. That is a

significant amount but still minute compared to China's total CO_2 emissions from oil product consumption of 799 million tonnes per year [32]. Thus, biodiesel's potential for greenhouse gas mitigation has to be realized in conjunction with those of other carbon-reduction means.

If land concession schemes are utilized but insufficiently monitored, they can lead to deforestation in surrounding areas, and the other gained environmental benefits, such as restored ecological functions and greenhouse gas mitigation, would be meaningless. There is increasing evidence that existing land concession schemes for biodiesel plantations in some countries are leading to forest clearance and the disruption of rural livelihoods. Many concessions are encroaching upon private properties and protected areas, allowing illegal logging, and leading to the shrinking of national forests. In such scenarios, even though the development of biodiesel as a clean substitute fuel may result in the reduction of greenhouse gas emissions, the benefits will be negated if forests continue to be cleared for plantations. It is critical that biodiesel crop plantations are sustainable and environmentally friendly.

5. Conclusions and recommendations

Biodiesel is a renewable and alternative fuel that has the potential to contribute toward sustainable development of many societies, especially developing countries. At the national level, biodiesel is one practical option that countries can add to their sustainable energy portfolios. Producible with local feedstock resources, biodiesel can help reduce oil imports, lower national trade deficits, and strengthen national energy security for oil-importing countries. Additionally, production and adoption of biodiesel as an alternative fuel can also create positive socioeconomic impacts, such as job creation, diversification and expansion of agricultural markets, and better standard of living. Furthermore, biodiesel also has environmental potential. The fuel, whose lifecycle can be carbon-neutral, creates cleaner emissions than does conventional petroleum-derived diesel.

Nonetheless, whether or not biodiesel's potential to contribute toward sustainable development is fully realized depends on how the fuel's production, usage, and other related activities actually affect the economy, society, and the environment. Besides the positive prospects, biodiesel developments sometimes also carry risks of environmental and socioeconomic problems. Since a typical biodiesel project, especially on a large scale, is multi-staged and involves many stakeholders, there are many aspects in which it can be susceptible to problems that hinder or counteract sustainable development, particularly in developing countries. Based on the viewpoints of stakeholders involved in biodiesel projects in the GMS, critical aspects of biodiesel developments are identified. These aspects are policy, governance, management, infrastructure, technology, feedstock, impacts on the rural poor and local livelihood, climate change, and the environment.

Within each critical aspect, important issues are analyzed. These issues must be considered and prepared for in the planning stages of biodiesel development, especially in developing countries, to ensure that the production and utilization of biodiesel actually contribute toward sustainable development. Within the policy aspect, there are issues of biofuels policy coherency, long-term development plans, strategies in specific areas, incentives to jump-start investment, the risks of land concession schemes, funding, and alternative routes toward sustainable development to be considered in conjunction with the biodiesel pathway. With respect to governance and management, the critical issues regarding biodiesel developments in developing countries include comprehensive management, stringent monitoring of land concession schemes' implementation, and management of large and potentially fragmented supply chains. In terms of infrastructure, the issues of appropriate scales and boundaries, incorporation of logistics, and assistance from private and international agencies are important. Because most biodiesel development in developing countries focus on technology and feedstock, developers tend to recognized the issues in this aspect more than the issues in others. Still, some issues may be overlooked, such as the yield-consistent feedstock crops, competition with food production, alternative uses and markets, and affordability and suitability of technologies. The issues regarding biodiesel development's impacts on rural poor and local livelihoods in developing countries are extremely important. Besides the prospects for enhanced income revenues and improved quality of life, there are the risks of unadvised and hasty investment, vulnerability to market fluctuation, and threats from exploitation of land concession schemes, such as encroachment on agricultural land, loss of land ownership, disruption of access to roads and water resources, loss of income, and social displacement. Lastly, there are also both prospects and pitfalls within the aspect of the environment and climate change. Although biodiesel crop planting has the potential for reforestation, restoration of ecological functions, and greenhouse gas mitigation, ill-managed biodiesel developments can fail to reach their potential or even harm the surrounding ecosystems, which are already fragile in developing countries.

Using biodiesel as an alternative fuel for transportation should not be considered as the sole contribution of biodiesel toward sustainable development. Developers and planners of biodiesel projects should not only focus on the means, but also be mindful of the ultimate goals. In other words, biodiesel should not be promoted simply because it can substitute conventional diesel. Instead, it should be promoted because it can lead society toward economic advancement, poverty reduction, energy security, carbon mitigation, biodiversity preservation, and climate change adaptation. With this perspective, one can realize more ways in which biodiesel can lead a society toward sustainable development. For instance, remote areas of many developing countries are still not connected to the electricity grid. Small-scale community-based biodiesel projects can help address basic energy needs for cooking, lighting, heating, etc., and with proper planning the projects can be carried out in socially, economically, and environmentally friendly ways.

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